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REMOTE SENSING OF COASTAL WETLAND VEGETATION AND ESTUARINE WATER PROPERTIES

by

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ABSTRACT

The advantages and limitations of remote sensing techniques for collecting synoptic data over large coastal and estuarine areas are reviewed with emphasis on the need for a proper balance between remotely sensed data and "ground truth". Specific applications presented include mapping wetland vegetation and coastal land use; monitoring natural and man-induced changes in the coastal zone; charting current circulation, including the movement and dispersion of known water pollutants; and determining the type and concentration of suspended matter in coastal waters. The photo-interpretation of aircraft and satellite imagery with the aid of "ground truth" is illustrated, employing both direct visual and automated computer techniques. For some applications, it is shown that an integrated boat-aircraft-satellite approach can produce better results or cost less, than the deployment of large numbers of boats or field teams without remote sensor support.

INTRODUCTION

Economic pressures to extract oil, to increase the harvest of food and to find new or maintain existing waste disposal sites are creating a need to understand the environment of large estuarine and coastal areas, including the entire Continental Shelf. The excessive amount of boat time and cost of ground crews required to collect synoptic data over such regions is causing investigators to look for more cost-effective means of performing this task. One technique which appears promising, involves the use of remote sensing, including standard aerial cameras and other sensors operating beyond the normal visual range of photographic films. The physical and technical aspects of imaging with remote sensors were reviewed by Colwell et. al. (9,10). Among the advantages enumerated are:

1. Wide area coverage, including regions with difficult access.
2. High resolution.
3. High cartographic accuracy with precision cameras.
4. Improved discrimination with multispectral sensors, including spectral bands outside the visible region.
5. Rapid, automated interpretation of imagery using optical and digital enhancement techniques.
6. Improved transmission, storage and update of the data in digital form.

The objective of this paper is to make estuarine and coastal investigators aware of the advantages and limitations of remote sensing techniques, including integrated boat-aircraft-satellite systems, to collect synoptic data over large coastal areas. The specific applications which will be reviewed include the following:

a. Mapping wetland boundaries and plant species.

b. Monitoring natural and man-induced changes in the coastal zone, including land-use and beach erosion.

c. Employing thermal or turbidity variations and remotely tracked drogues or dyes to chart current circulation patterns, including the movement and dispersion of known water pollutants.

d. Determining the type and concentration of certain suspended and dissolved substances in estuaries, including surface and subsurface pollutants.

Imagery obtained from aircraft and satellites will be interpreted with the aid of "ground truth" collected from helicopters and boats. Direct visual photo-interpretation and automated computer techniques will be illustrated.

MAPPING WETLAND BOUNDARIES AND PLANT SPECIES

The commitments to environmentally sound coastal land management that have been generated in federal and state governments over the past few years have produced a demand for accurate and complete bodies of scientific data on which to base policy decisions. Inventories of wetlands are now specifically required by individual state laws, such as the New Jersey Wetlands Act of 1970, the Maryland Wetlands Act of 1970, and the Delaware Wetlands Act of 1973. Further incentive to coastal states to inventory and manage their coastal resources was provided by the Coastal Zone Act of 1972. Since plant species composition appears to be a good indicator of relative marsh value and also of the wetlands-uplands boundary, wetlands vegetation is currently being mapped using various techniques, most of them involving remote sensing. (3,24,44).

Coastal wetlands of the type found along the East and Gulf coasts of the United States are well suited to remote sensing techniques. The uniform flatness of marsh topography eliminates variations in reflectance due to sloping surfaces and shadows. The most common marsh plant species are few in number, thus simplifying photointerpretation. Environmental changes generally take place over large horizontal distances in the marsh. Therefore, zones of relatively uniform vegetation are usually large enough to be discernible, even on very high-altitude imagery. Finally, the major plant species are different enough in their morphologies to have distinct reflectance characteristics, particularly in the near-infrared portion of the spectrum. The net result is that aerial photographs can be used to make detailed wetlands map showing vegetation growth patterns which are related to local environmental factors. (2,29,44).

Most of the wetlands mapping is being performed at scales of 1:2,400 and 1:24,000. A scale of 1:2,400 is usually employed to define the "legal" wetlands-uplands boundary and inventory the plant species composition. The maps contain considerable detail and at that scale can be readily related to local zoning or taxation maps. The maps are generally prepared by direct photointerpretation of color and color-infrared prints and transparencies obtained from low-flying aircraft. In the case of the Delaware wetlands mapping the photographs were taken from an aircraft altitude of 6,000 feet with six-inch focal length cameras, producing nine-inch original photographs at a scale of 1:12,000. The nine-inch color transparencies were then used to make 5x black-and-white enlargements on stable "Mylar" film material at a scale of 1:2,400. The lines separating the plant species and the wetlands from the uplands were next drawn in on the enlargements by photointerpreters using the original color and color-infrared prints and supporting data from ground surveys. Since these maps will constitute a legal definition of the wetlands boundaries, highest map accuracy standards must be maintained and accuracy limitations well known.

On the other hand a scale of 1:24,000 is being used by many investigators and agencies to map land cover and land use for planning coastal development and managing coastal resources. These maps are somewhat easier and less expensive to prepare than the detailed wetlands maps for several reasons. The scale is smaller, requiring considerably fewer maps to cover the same area. For instance, to map Delaware's 115,000 acres of wetlands at a scale of 1:2,400 required 360 maps, whereas fifteen maps sufficed at a scale of 1:24,000. Since base maps already existed at a scale of 1:24,000, such as USGS topographic maps, only overlays of the vegetation species were prepared, eliminating the need for expensive geometric corrections and ground grid controls. Figure 1 shows a typical overlay map at a scale of 1:24,000 of ten plant species in the wetland region around Taylor's Bridge, Delaware. While primary and secondary species were identified by visual photointerpreation, percentages of minor species in each of the rectangular areas were obtained by automated computer techniques using the General Electric Multispectral Data Processing System (GEMS), a hybrid analog/digital system permitting man-machine interaction at nearly real-time rates. (29). A modified color TV camera scans the color transparency and produces three video signals representing the red, blue and green spectral components of the image. The output from the camera is displayed on a color monitor. The human interpreter selects the area of interest and then employs various available electronic data processing techniques to identify the spectral characteristics of the area, search the scene for areas with similar spectral signatures, and compute the percentage of the total scene occupied by these areas. The fact that most coastal plant species differ in their spectral signatures, i.e. the amount of light they reflect at various wavelengths, forms the basis for their discrimination by remote sensors using multispectral techniques.

A relationship between spectral reflection characteristics and productivity of certain marsh plant species has been found, making it feasible to map marsh productivity remotely. (44). However, large amounts of "ground truth" are required and the reliability of the technique leaves much to be desired.

MONITORING LAND-USE AND COASTLINE CHANGES

Monitoring natural changes, such as beach erosion, or man-made changes, such as land-use, requires repetitive photographic coverage of the coastal zone either by aircraft or satellites. (41) Fortunately, aircraft from the U. S. Coast and Geodetic Survey or from the U. S. Department of Agriculture, Agricultural Stabilization and Conservation Service (ASCS) have photographed many coastal regions, at least once per decade since 1938. Figures 2, 3 and 4 show three black-and-white aerial photographs of the Indian River Inlet area in Delaware, obtained in 1938, 1954 and 1968, respectively. Reshaping of the inlet and construction of the jetty is causing accretion of sand south of the inlet and erosion north of it, with imminent danger to the highway above it. To map the coastline change accurately one could use the procedure described in reference 47 consisting of selecting stable reference points on the aerial photographs taken in different years and measuring the distance between these points on the transient beach. The measurements obtained are then multiplied by the scale of the aerial photographs to produce ground distances. The differences in ground distances determined from aerial photographs taken with several years of time lapse represent the change in location of the beach over the period of the time lapse. As a final step one can attempt to relate the volume of material eroded to the linear distances of beach erosion perpendicular to the beach.

Color, color-infrared or black-and-white photographs such as shown in Figures 2, 3 and 4 can be used to map land use change. The most effective way to accomplish that is to map the land use for each year represented by the photographs on an overlay superimposed on a base map. To compensate for scale differences between the photographs and the base map one can use a Zoom Transfer Scope (ZTS) or similar viewing system. For instance, the Bausch and Lomb ZTS enables the user to view both an aerial photograph and a topographical map of the same area. Simplified controls allow the matching of differences in scales and provide other optical corrections so that the two images appear superimposed. Information from the photograph may then be compared or traced onto the map.

Satellites, such as NASA's LANDSAT-1, offer wider and more regular coverage than aircraft. (16,28). For instance, LANDSAT-1 passes over the Delaware Bay test site every 18 days, and even if on the average two out of three passes are obscured by cloud cover, a successful pass every 54 days is more than sufficient to detect changes in coastal land-use. From an altitude of 920 km, the satellite uses a four-channel Multispectral Scanner (MSS) and a Return-Beam Vidicon Camera to image an area of 185 x 198 km in each frame. The location and bandwidths of the four MSS channels are shown in Table 1.

TABLE 1

LANDSAT MSS Bands

Band No.	Wavelength Range (Microns)
4	0.5 - 0.6
5	0.6 - 0.7
6	0.7 - 0.8
7	0.8 - 1.1

Several investigators have successfully used LANDSAT-1 to monitor coastal land-use and its changes. (14,15,16,29). The large amount of data generated from repetitive coverage and the digital tape format of the satellite data make it attractive to analyze it with computers using multispectral techniques. (28,45). For instance, digital LANDSAT-1 MSS scanner data and SKYLAB photographs have been used in an attempt to inventory and monitor significant natural and man-made cover types in Delaware's coastal zone. Automatic classification of LANDSAT data yielded classification accuracies of over 83 per cent for all categories shown in Table 2. (28). The classification accuracy of several important categories is shown in Table 3.

TABLE 2

Vegetation and Land-Use Categories

1. Forest land.
2. *Phragmites communis* (Reed grass).
3. *Spartina patens* and *Distichlis spicata* (Salt marsh hay and spike grass.
4. *Spartina alterniflora* (Salt marsh cord grass).
5. Cropland.
6. Plowed cropland.
7. Sand and bare sandy soil.
8. Mud and asphalt.
9. Saline deep water.
10. Sediment laden and shallow saline water.

TABLE 3

Classification Accuracy Table Derived by Comparison of LANDSAT Thematic Data with NASA-RB-57 Aircraft Photography

Category	Forest	S. alt.	S. pat.	Water	Agriculture
Forest	89.9%	0.0%	4.5%	0.0%	5.6%
Spartina alterniflora	0.0%	93.7%	5.7%	.6%	0.0%
Spartina patens	0.0%	7.7%	87.0%	2.2%	3.0%
Water	0.0%	2.6%	3.9%	93.5%	0.0%
Agriculture	3.5%	0.3%	2.1%	0.0%	94.1%

Visual interpretation of Skylab Earth Terrain Camera photographs distinguished a minimum of 10 categories with classification accuracies ranging from 75% to 99%. (28). A land-use map derived from SKYLAB imagery is shown in Figure 5. Note that the scale is 1:125,000. Maps derived from satellite or spacecraft imagery scales generally have scales smaller than 1:100,000. Thus, to obtain wide area coverage from satellite altitudes, one must give up the detailed resolution attainable from aircraft imagery. The size of the smallest resolvable object at high contrast is about 80 meters for LANDSAT, 20 meters for SKYLAB and less than 1 meter for most mapping aircraft altitudes.

Various land-use classification schemes have been proposed by individuals and agencies. (1). Most investigators are adopting the Federal Land-Use Classification System for the upper levels and modifying the lower level categories to suit the needs of their application and geographic region. Once a user has selected the classification categories, he can instruct a computer to perform "supervised" or "unsupervised" classification of the imagery. Supervised classification begins with identifying certain sets of resolution cells within a scene that represents known classes of categories on the ground. These groups of cells are known as training sets. The spectral responses in the spectral channels of each training set provides the information needed to identify the remaining cells in the image. The "decision rules" that are used to identify the class of each cell are defined by the user.

Non-supervised classification randomly selects resolution cells within the scene. The spectral characteristics of these random points eventually provide the statistics for classifying remaining cells. Simply stated, a sample cell is either placed in a cluster with other sample cells of similar spectral responses, or it forms the core of a new cluster. These sample-derived clusters provide the statistics used to classify the remainder of the scene. However, each computer-aided data processing and interpretation approach still requires that a human interpreter be "in the loop" to verify the final results.

Both visual and computer-aided interpretation of imagery requires some "ground truth" data, i. e. a minimum amount of information about the area being imaged. As a result, remote sensing techniques do not eliminate the need for ground surveys, but only decrease significantly the amount of field data required.

CHARTING CURRENT CIRCULATION AND POLLUTION DISPERSION

In the ocean, where scattering and absorption effects are the same order of magnitude, the penetration depth of visible light may exceed 50 meters. (20,51). In tidal estuaries and coastal waters, scattering by suspended matter becomes severe, resulting in penetration depths and Secchi depths of the order of a few meters. As a result, it is difficult to use remote sensors to map bottom contours in coastal waters. Laser profilers with the help of intense light beams can penetrate to several times the Secchi depth, but that is still insufficient to chart the depth contours in most estuaries. (5,19).

Remote sensors are also limited to a narrow band in the visible region since other wavelengths, such as the ultraviolet or infrared, are strongly absorbed by the water. Therefore, multispectral photography and analysis over wide ranges of the electromagnetic spectrum cannot be applied as readily to sensing substances in water as it has been over land. The attenuation coefficients for distilled, oceanic and coastal waters are plotted in Figure 6. Note that as one goes from deep ocean to coastal conditions, the attenuation not only increases, but the wavelength for best penetration also shifts from the blue towards the green and red.

Water features tend to change more rapidly than those on land, especially in tidal estuaries. For instance, at the mouth of Delaware Bay water samples from ships or helicopters must be obtained within 20 minutes of a satellite overpass to be valid as "ground truth" for suspended sediment mapping, compared to an acceptable delay of several weeks for vegetation inventories. Despite these problems, remote sensing techniques are being applied to attempt to chart the current circulation and dispersion of known pollutants; to map the concentration of suspended matter and thickness of certain films; and to determine the identity of unknown slicks and suspended matter.

Current circulation patterns have been studied remotely by time photography of current drogues, tracer dyes, natural tracers, such as suspended sediment, or thermal gradients. (23,31,36,46). Surface water movement studies utilizing fluorescent tracer dyes have been conducted on most of the major surface water bodies and near coastal waters of the United States. These studies have been conducted to determine the dynamic characteristics of the water bodies with the primary objective being to trace the current flow rate and direction and the rate of dispersion. (49). Systems used to monitor tracer dyes are visual inspection, photographic recording, grab sample collection and laboratory analyses, continuous field sampling and recording with flow-through fluorometers, field measurements with a submersible pulsed light fluorometer, and remote measurements of dye concentrations from an aerial platform.(13) Rhodamine B and Rhodamine WT are two of the more commonly used dyes, having specific gravities at room temperature of 1.12 and 1.19, and maximum emission wavelengths of 0.579 microns and 0.582 microns, for solutions of 40% to 20%, respectively.

Rhodamine WT dye can be tracked for several hours by low altitude aircraft carrying color cameras. (31) After several hours, however, the dye is diluted to concentrations that can be discerned only by aircraft cameras with special optical filters that are optimized for the spectrum of each dye used. This is particularly true for dye experiments in coastal waters. The emission spectrum of Rhodamine WT and the spectral transmission of suitable filters are shown in Figure 7. The Wratten 73 is a band-pass filter with its transmission band closely matched to the spectral emission maximum of Rhodamine WT. Field tests, however, showed that the Wratten 25A filter was more effective in enhancing the dye patches. (31). This result could be partly explained by Eliason and Foote's (13) observation that dyes at high concentrations are self-absorbing, which causes the effective peak of the dye fluorescence line to shift to longer wavelengths. Therefore, the dye was tracked from aircraft that carried cameras containing Kodachrome-X film with Wratten 1A Skylight filters and Tri-X film with Wratten 25A filters. Aircraft altitudes ranged from 300 to 1,000 m.

The drogues shown in Figure 8 are small, compact units which can be dropped and tracked from low-flying aircraft. Their basic design does not differ significantly from that of drogues used by various investigators during the past few decades. (40). These small drogues are deployed whenever a detailed charting of current circulation over a realatively small area, such as four square miles, is desired. As shown in Figure 8, the drogues consist of a styrofoam float and line to which is attached a current trap consisting of a stainless steel biplane. The length of the line determines at what depth currents will be monitored. The floats are color-coded to distinguish their movement and mark the depth of the biplanes. Packs with dyes of two different colors can be attached to the float and the biplane. (30). The movement of the dye and drogues is tracked by sequential aerial photography, using fixed markers on shore or on buoys as reference points to calibrate the scale and direction of drogue movement. The results of a combined dye and drogue experiment at the mouth of Delaware Bay are illustrated in Figure 9. As shown, subsurface currents differed significantly from surface currents during both the ebb and the flood tidal cycles. (31)

Satellites, such as LANDSAT-1 have been used to obtain a synoptic view of current circulation over large coastal areas. (27,36,43). Since in turbid coastal regions suspended sediment acts as a natural tracer, cost is minimized by eliminating the need for expensive injections of large volumes of dye such as Rhodamine-B. Figure 10 shows the LANDSAT-1 MSS band 5 image and predicted tidal currents of a satellite overpass on February 13, 1973, about one hour after maximum ebb at the mouth of Delaware Bay. The intensity variations throughout the bay are caused by suspended sediment, and not bottom contours, since the actual water depth in most areas was at least three times the Secchi depth. Strong sediment transport out of the bay in the upper portion of the water column is clearly visible, with some of the plumes extending up to 30 km out of the bay. The northward curvature of small sediment plumes along New Jersey's coast clearly indicates that the direction of the nearshore current at that time was towards the north. The wind velocity at the time of the satellite overpass was about 13 km per hour from the west-northwest, reinforcing the tidal current movement out of the bay.

The suspended sediment and current circulation patterns in Figure 10 can be significantly enhanced not only by careful print development, but also by multispectral enhancement techniques such as color density slicing and color additive viewing. Color density slicing breaks up gradual grey tone variations into digital steps and converts each grey tone step into a distinct color, helping the eye recognize subtle grey tone changes. This is effective because the average human eye can distinguish over 100 color hues while it can only discriminate about a dozen grey scale levels. Color additive viewing involves the exact superposition of transparcencies of the same scene obtained with different filter film combinations. Both enhancement techniques have been used with some success to improve the contrast of water features.(27,33,38,53).

One of the principal shortcomings of satellite imaging of coastal currents has been the inability to determine current magnitude and to penetrate beyond the upper few meters of the water column. These objections have been overcome by complementing satellite observations with drogues tracking currents at various selected depths. (30). One type of drogue used was developed by ITT-Electro Physics Laboratories and emits a radio signal which is tracked from shore. The drogue consists of a plastic pipe less than two inches in diameter, with all of its electronics and antenna totally enclosed within the pipe (Figure 11). It is also provided with a water temperature sensor. A current trap (biplane) is attached to the bottom of the drogue and can operate at a variety of depths from about one meter to a hundred meters. The intended radiated power of the drogues is such that the position of each drogue can be fixed by triangulation from shore with a mobile antenna over a range in excess of 300 km, with an accuracy approaching $\pm$ 0.5 degree. By combining the satellites' wide coverage with aircraft or shore stations capable of tracking the expendable drogues, a cost-effective, integrated system has been devised for monitoring currents over large areas, various depths and under severe environmental conditions. (30).

Aircraft and satellites, supported by water sampling conducted from boats, have also been used to study the movement and dispersion of various pollutants in estuarines and on the Continental Shelf. (4,32,42,50). Approximately forty nautical miles off the Delaware coast is located the disposal site for waste discharged from a plant processing titanium dioxide. The discharge is a greenish-brown, 15% to 20% acid liquid which consists primarily of iron chlorides and sulfates. The barge which transports this waste has a 1,000,000 gallon capacity and makes at least three trips to the disposal site per month. The frequency of this dumping made it possible for the LANDSAT-1 satellite to image the acid plume in various stages of degradation, ranging from minutes to days after dump initiation. (30). Nine photographs were found which show water discoloration. The dump pattern and the time difference between the dump and photograph give strong indications that the discolorations are the acid plume. Careful examination of an overpass on January 25, 1973, disclosed a fishhook-shaped plume about 40 miles east of Cape Henlopen caused by a barge disposing acid wastes. The plume shows up more strongly in the green band than in the red band, due to the iron content of the discharge. Enlarged enhancements of the acid waste plumes, prepared from the LANDSAT-1 MSS digital tapes (Figure 12) aided considerably in studies of the dispersion of the waste plume. Currently acid dumps are being coordinated with LANDSAT-1 overpasses in order to determine the dispersion and movement of the waste materials along the Continental Shelf. Sludge disposal plumes in the ocean off the Delaware coast and in the New York Bight have also been detected in LANDSAT-1 imagery. (38).

Thermal scanners on various platforms are frequently employed to chart current circulation patterns in the ocean and to study specific thermal effluent plumes. (46,48). The accuracy of such thermal maps is of the order of $\pm$ 1°C without "ground truth" and about $\pm$ 0.2°C with calibration provided by surface water temperature measurements.

DETERMINING THE CONCENTRATION AND IDENTITY OF WATER POLLUTANTS

It is far more difficult to remotely sense the concentration and identity of an unknown pollutant than to monitor the movement and dispersion of a known substance. Oil is one example. Oil slicks have been tracked successfully with remote sensors employing the ultraviolet, visible, infrared and microwave regions of the electromagnetic spectrum. (6,26). Both passive and active sensors are being used, such as film cameras and ultraviolet lasers, respectively. The least expensive means of tracking oil slicks is from a single engine aricraft with a camera using color film or a sensitive black-and-white film, with an ultraviolet filter (e.g. Tri-X film with Kodak Wratten 18A filter). However, except for partially successful attempts under controlled conditions, no reliable technique has yet been developed for remotely determining oil slick thickness, the concentration of emulsified oil, or the type of oil in a slick.

At the beginning of this paper, I pointed out that one of the most effective ways to identify and discriminate certain vegetation and land-use types was by their spectral signatures. This technique is more difficult to apply to substances in water, due to complex mixing, multiple scattering and absorption processes, especially in coastal waters. (17,20,39). For instance, approximate chlorophyl concentrations have been mapped remotely near upwelling regions of the oceans, but whenever the chlorophyl is mixed with suspended sediment in estuarine or near-shore areas, its assessment becomes extremely complicated. (4,7). Therefore, it is not surprising to find that the spectral signature of a substance in water may differ as much from its own signature obtained under slightly different conditions (sun angle, sea state, depth, etc.) as it differs from that of another substance. This sensitivity of spectral signatures to small changes in environmental or imaging conditions, tends to make remote sensing of water substances heavily dependent on a well-coordinated ground truth acquisition program including water sampling at various depths from boats or helicopters. (33,52).

The suspended sediment concentration map in Figure 13 illustrates what can be accomplished with proper ground truth data. The image radiance was extracted from computer compatible digital tapes comprising a LANDSAT-1 MSS band 5 image of the Delaware Bay similar to the one shown in Figure 10. The image radiance was then correlated with data obtained from water sample analyses of suspended sediment concentration.(27). Since a high degree of correlation was obtained, the map in Figure 13 was prepared, showing the suspended sediment concentration in the upper one meter of the entire Delaware Bay area. Other investigators are combining several of the LANDSAT MSS bands to map suspended sediment concentrations. (21,52).

GENERAL CONSIDERATIONS AND PRACTICAL ADVICE

The most frequent question I have encountered during lecture tours concerns the availability of imagery for a given area, how to obtain it and how to arrange for future remote sensing overflights. In addition to aerial photographs at USGS, USDA and state agencies, the U. S. Deparment of Interior's Sioux Falls Data Facility has on file imagery of almost every coastal area of the country. Some regional NASA centers have an interest in providing local investigators with mapping overflights if such flights can be made part of another, contracted mission. Help from Air National Guard units and state police aircraft can be solicited. For cartographic applications, one may have to hire a commercial company to perform precision overflights. On the other hand, for rough surveys, renting a single-engine plane and using hand-held 35mm cameras may suffice. The rental of single-engine aircraft in Delaware is about

$35 per hour. We save about 30% of this cost by providing our own pilot. Any high-wing aircraft, such as the Cessna 150 or Cessna 172 should be suitable. To gain additional field of view, during good weather, it helps to remove the door on the photographers side of the plane. Film and filter combinations should be selected specifically for each application. However, contrast is generally improved if skylight or haze filters are used to eliminate the ultraviolet and a portion of the blue light.

Single-engine, non-pressurized aircraft are limited to altitudes below 12,500 feet and must stay within gliding distance of the shoreline. Since the cost of using twin-engine aircraft or helicopters is three times higher, single-engine aircraft can still be used at considerable distances from shore, if they are in close proximity to boats. Safety considerations and the collection of useable ground truth data dictate that a reliable aircraft-ship-shore communication system be used, including back-up radio channels in case of main channel failure. Furthermore, on some missions, in addition to a pilot and a photographer, a third crew member is desirable for keeping a log of camera frames, visual observations, and sketching rough maps to aid the subsequent photointerpretation of the aerial photographs.

SUMMARY AND CONCLUSIONS

Remote sensing techniques have been applied with varying degrees of success to accomplish the following in the coastal and estuarine areas:

- mapping wetland boundaries, plant species diversity and productivity.
- monitoring man-made and natural changes in the coastal zone, such as land-use change and shoreline erosion.
- charting current circulation and pollutant dispersion, including slicks and suspended matter.

- determining the identity and concentration of certain natural and man-made pollutants.

Imaging suspended matter or other subsurface features in water is more difficult than mapping surface slicks or land-use cover because of complex mixing, scattering and absorption processes in the water column. The failure of remote sensors to penetrate beyond a few meters into turbid coastal waters makes it difficult to map bottom contours or track near-bottom sediment transport. Wavelengths outside the visible region are strongly absorbed in the water column, diminishing the value of ultraviolet and infrared bands, which are used quite effectively for surface slick and land-cover discrimination.

Closely coordinated ground truth collection programs are required for most remote sensing efforts, especially for the assessment of marsh productivity, the identification of water pollutants and the mapping of their concentration. In general, the acquisition of data from aircraft or satellites has not eliminated the need for data collection from ships and by ground survey teams, but well coordinated remote sensing efforts have significantly decreased the number of samples that have to be collected on the ground, resulting in cost savings on ship time and ground personnel.

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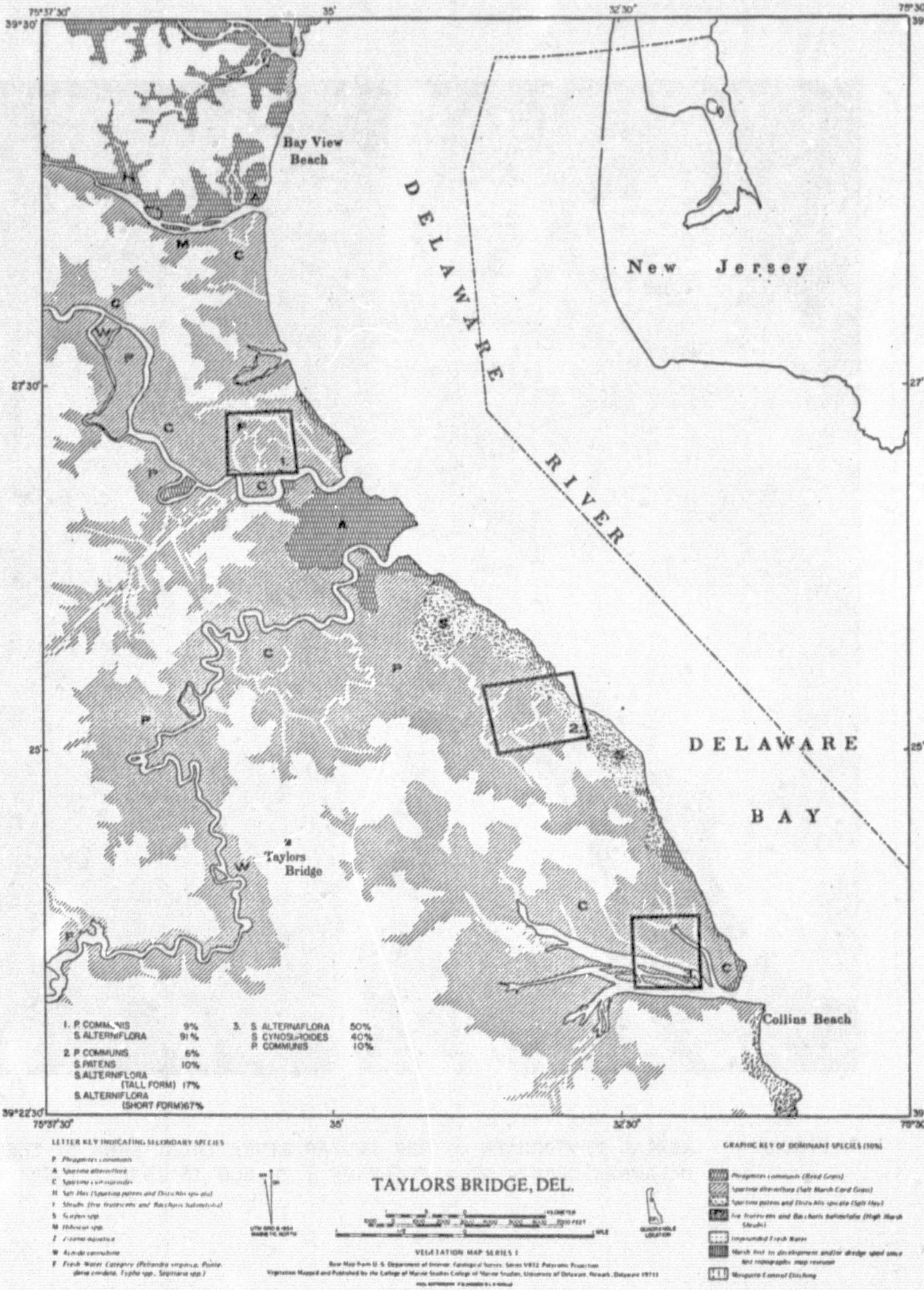

FIGURE 1. OVERLAY MAP SHOWING TEN SPECIES OF MARSH VEGETATION, DITCHING, IMPOUNDED WATER, AND MARSH LOST TO DEVELOPMENT. FIFTEEN SUCH MAPS COVERING DELAWARE'S WETLANDS HAVE BEEN PREPARED USING MULTISPECTRAL ANALYSIS OF RB-57 IMAGERY.

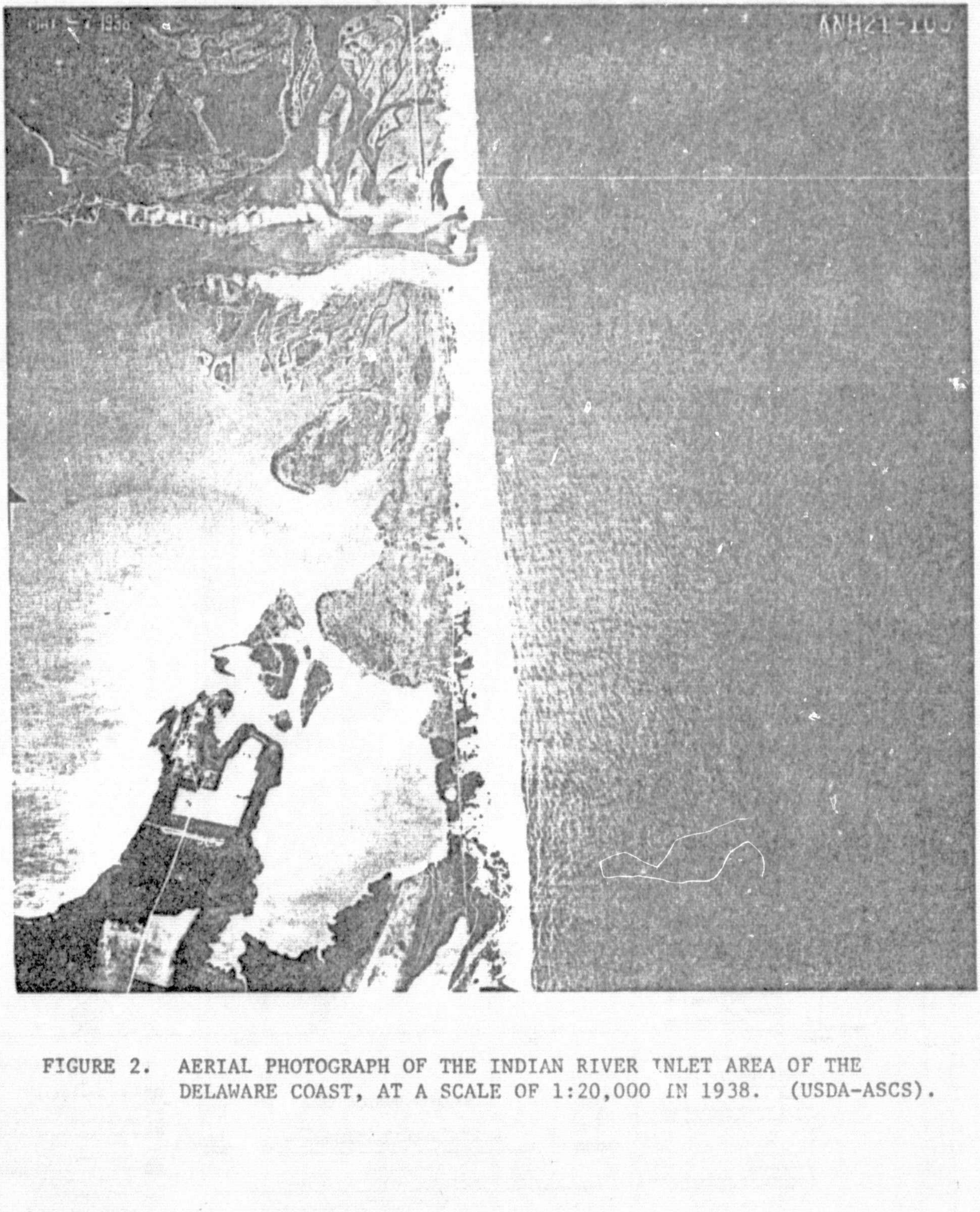

FIGURE 2. AERIAL PHOTOGRAPH OF THE INDIAN RIVER INLET AREA OF THE DELAWARE COAST, AT A SCALE OF 1:20,000 IN 1938. (USDA-ASCS).

FIGURE 3. AERIAL PHOTOGRAPH OF THE INDIAN RIVER INLET AREA OF THE DELAWARE COAST, AT A SCALE OF 1:20,000 IN 1954. (USDA-ASCS).

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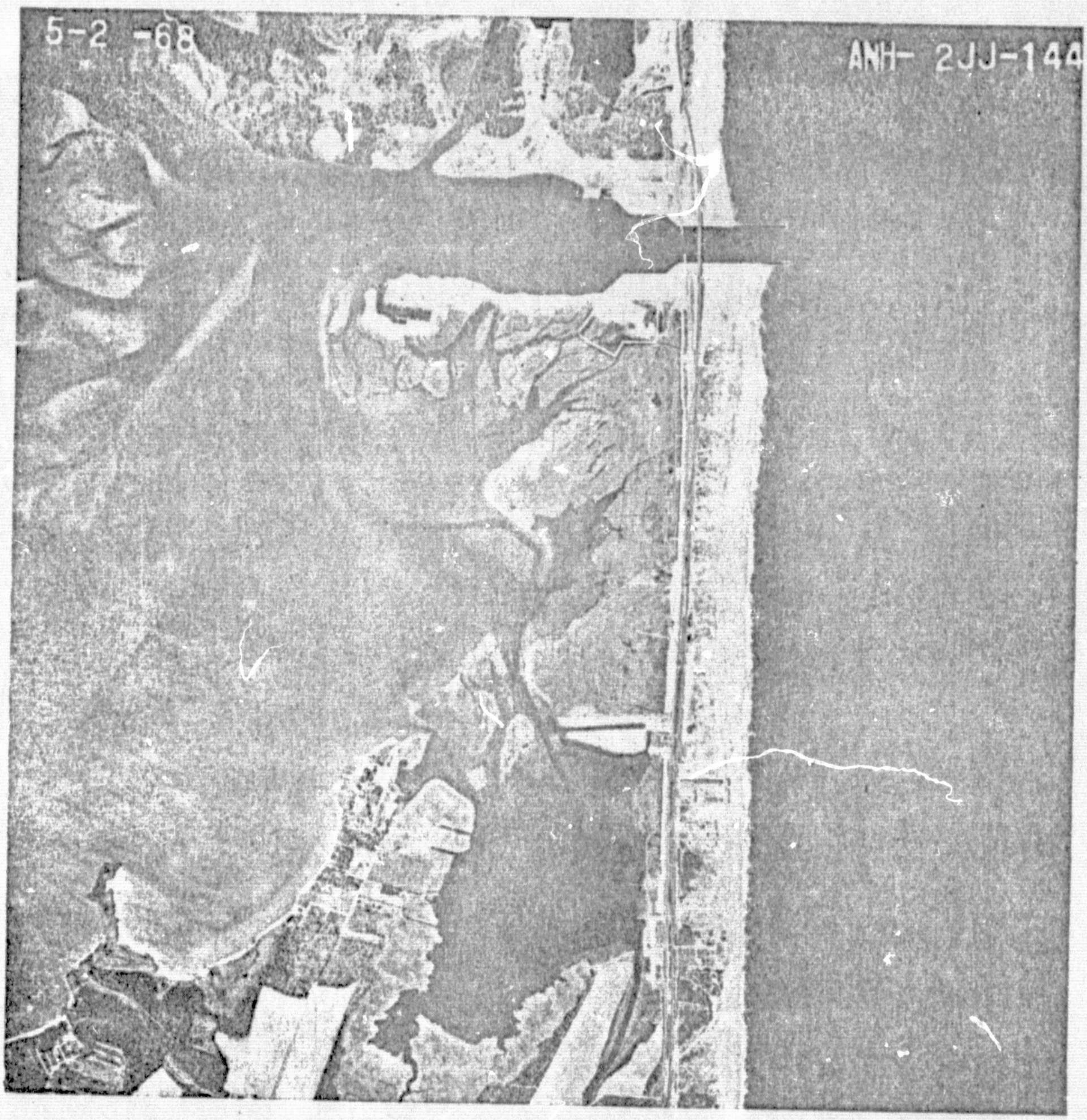

FIGURE 4. AERIAL PHOTOGRAPH OF THE INDIAN RIVER INLET AREA OF THE DELAWARE COAST, AT A SCALE OF 1:20,000 IN 1968. (USDA-ASCS).

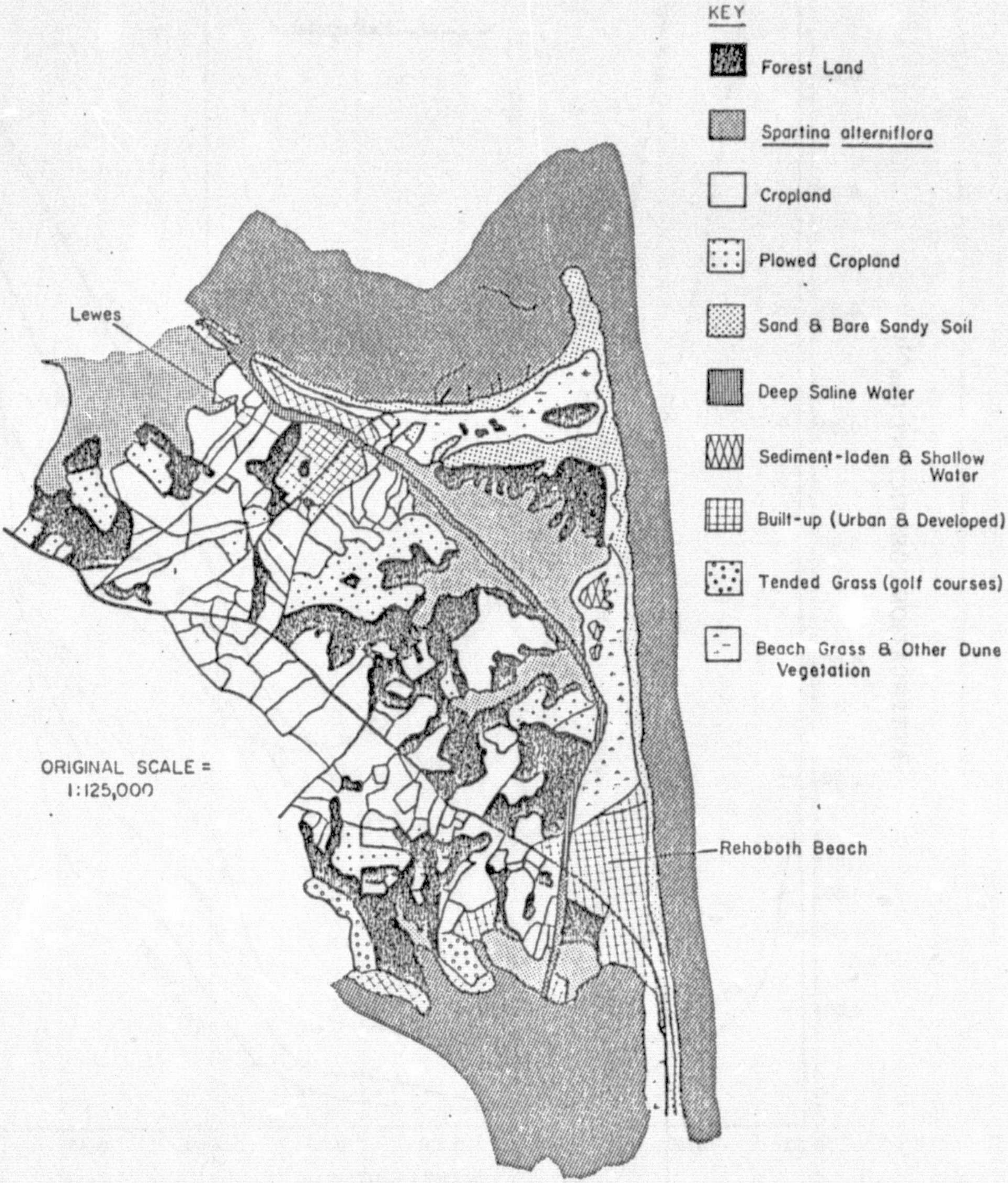

FIGURE 5. LAND-USE MAP DERIVED FROM SKYLAB/EREP IMAGE BY VISUAL PHOTO-INTERPRETATION.

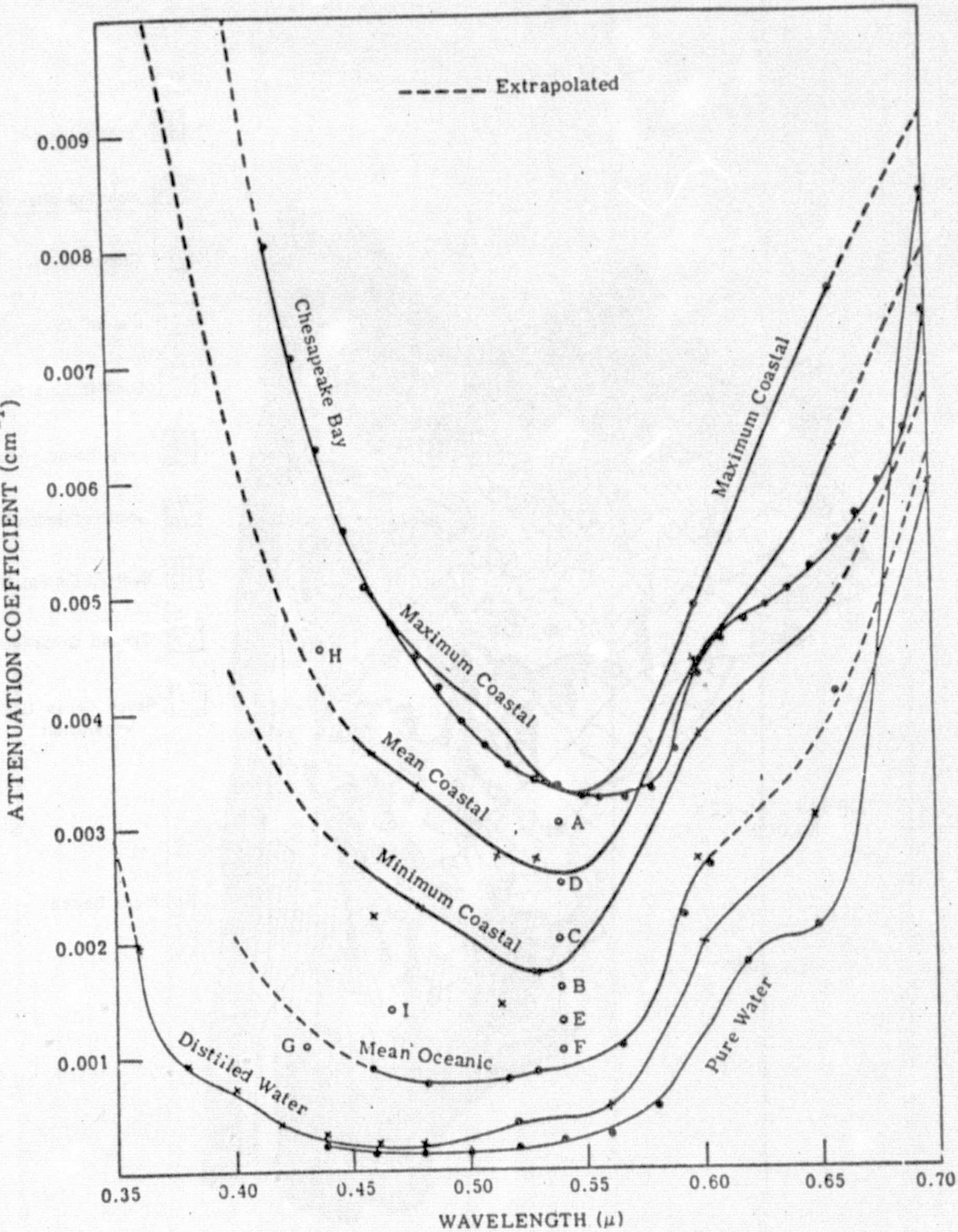

FIGURE 6. ATTENUATION COEFFICIENT VERSUS WAVELENGTH FOR PURE WATER AND SEA WATER.

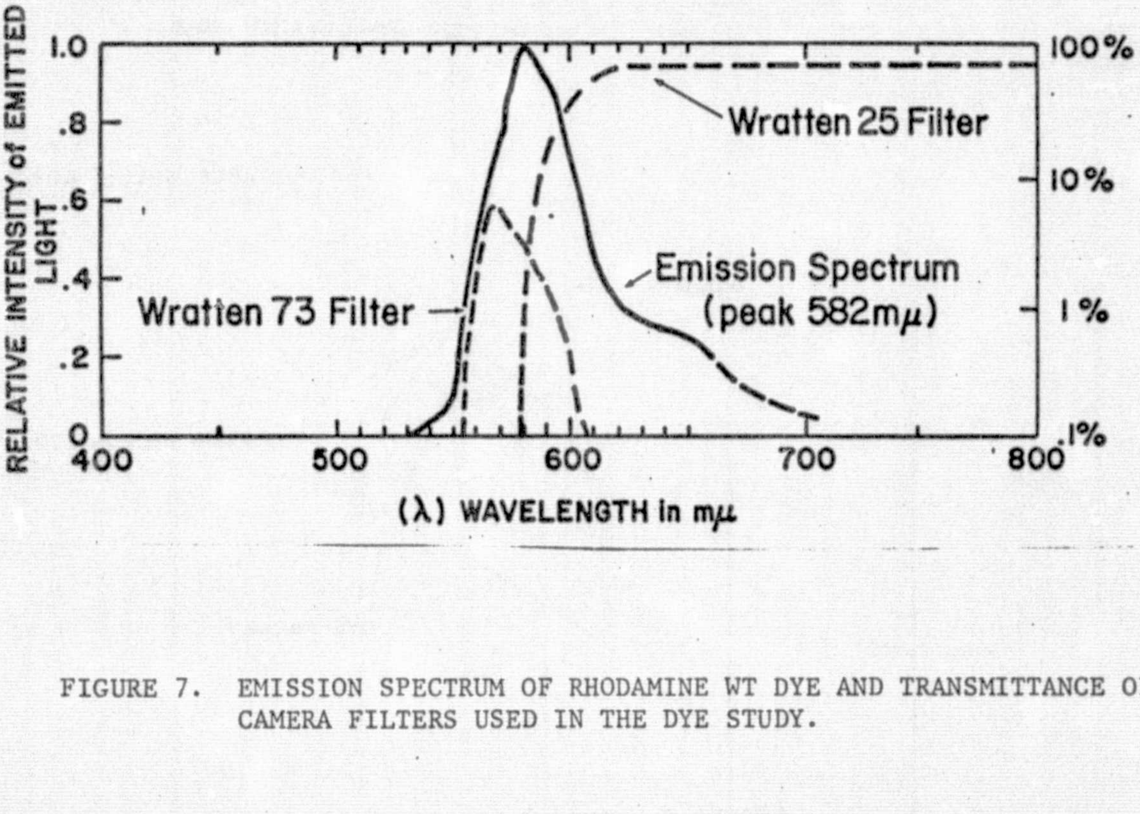

FIGURE 7. EMISSION SPECTRUM OF RHODAMINE WT DYE AND TRANSMITTANCE OF CAMERA FILTERS USED IN THE DYE STUDY.

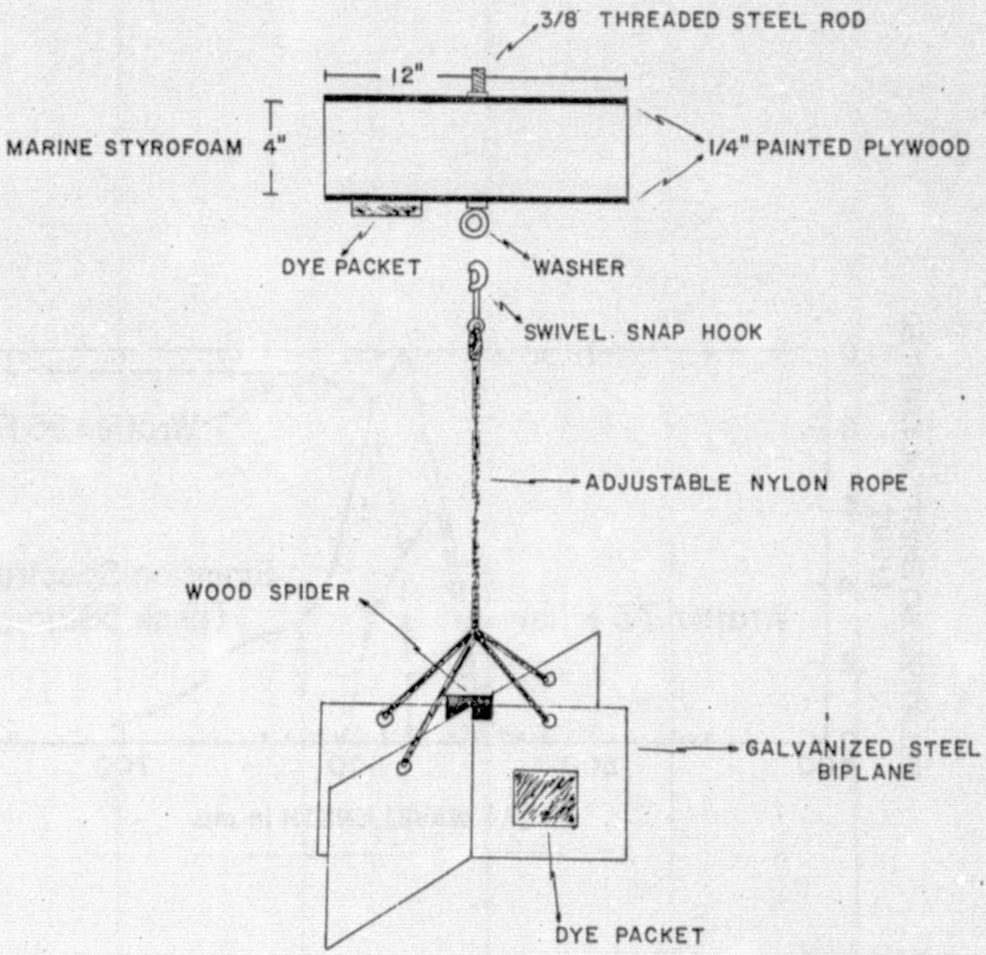

FIGURE 8. DROGUE AND DYE EXPERIMENTAL PACKAGE.

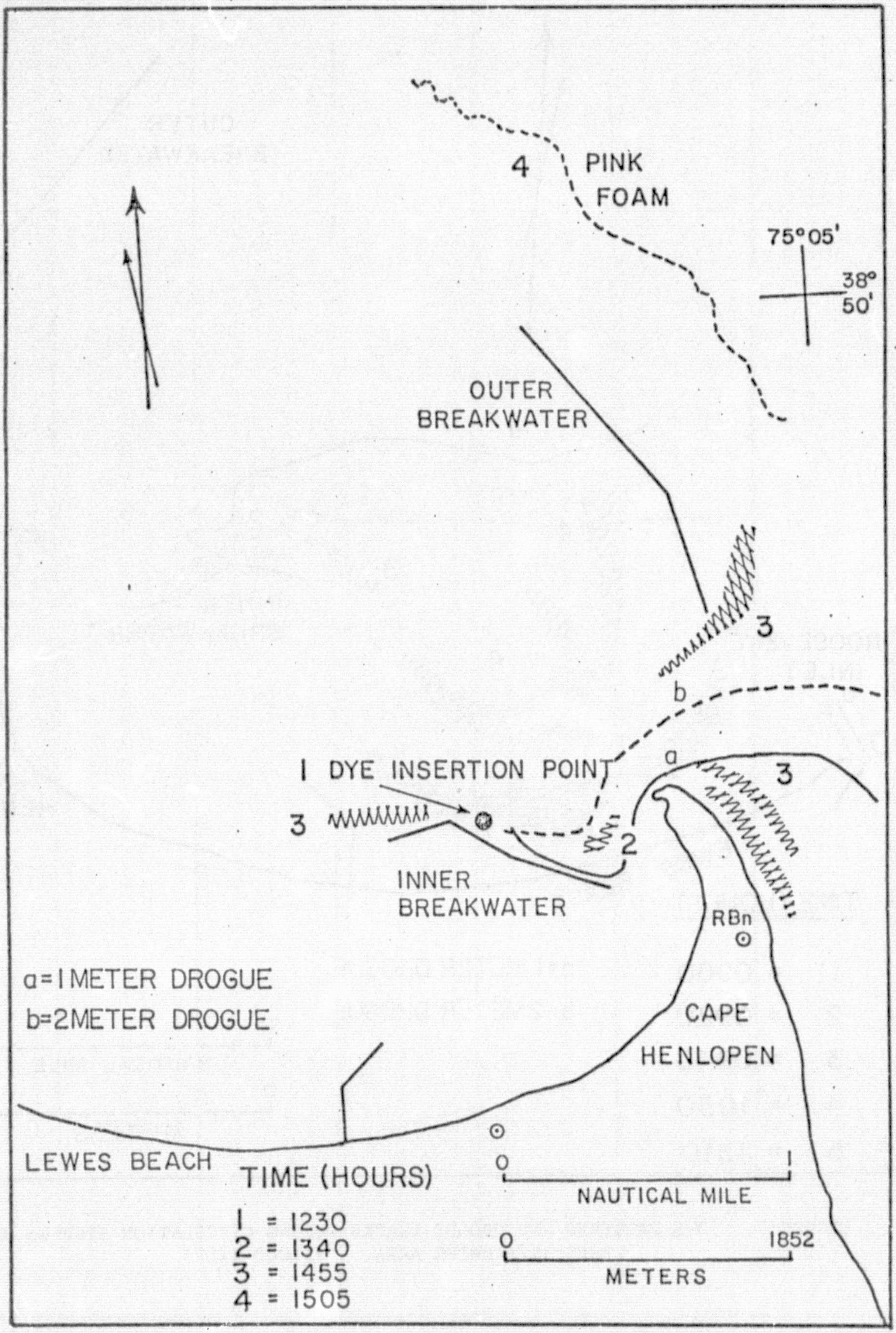

FIGURE 9a. DYE PATTERNS AND DROGUE TRACKS DURING CIRCULATION STUDIES IN THE LEWES BREAKWATER AREA. (EBB TIDE)

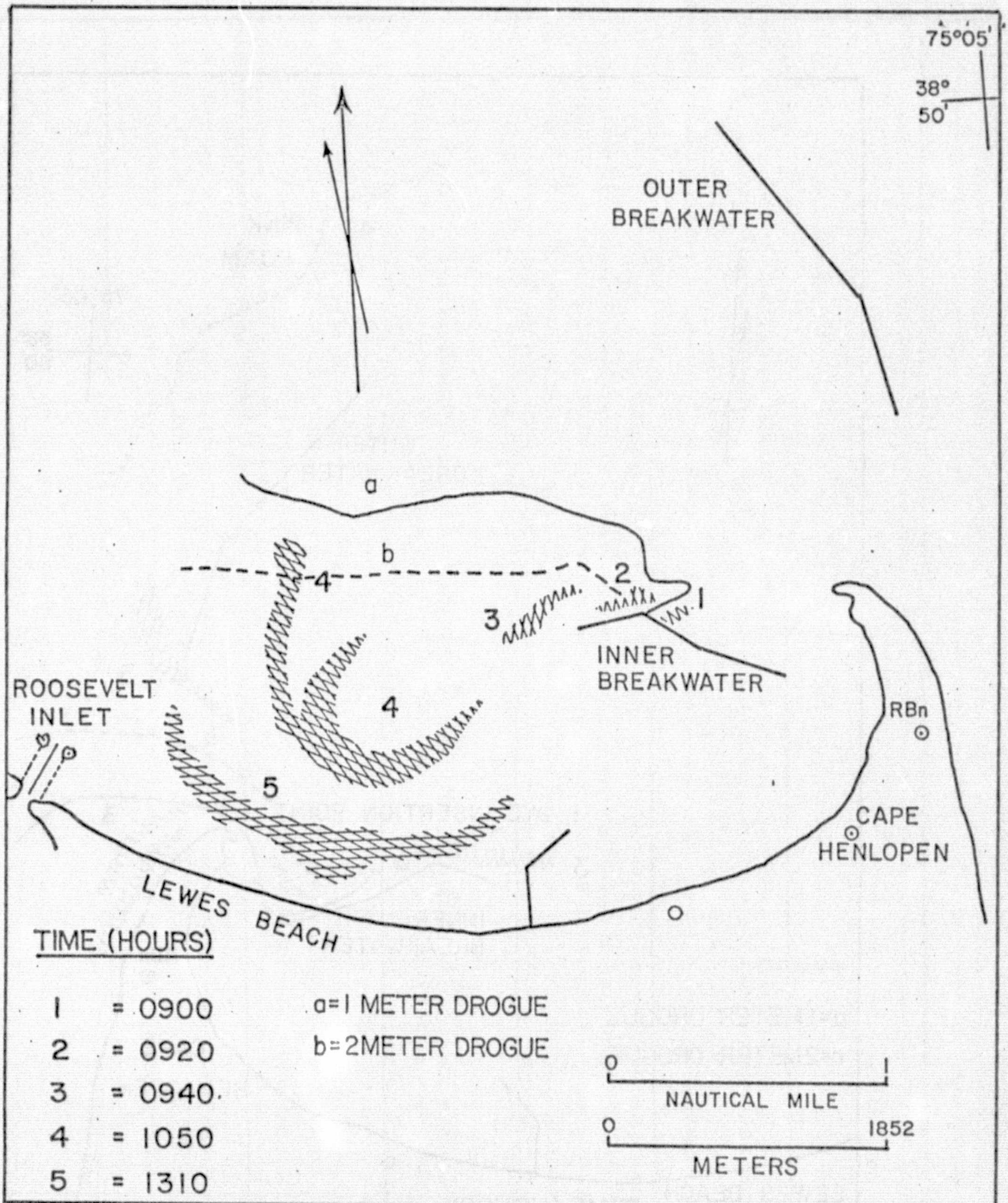

FIGURE 9b. DYE PATTERNS AND DROGUE TRACKS DURING CIRCULATION STUDIES IN THE LEWES BREAKWATER AREA. (FLOOD TIDE)

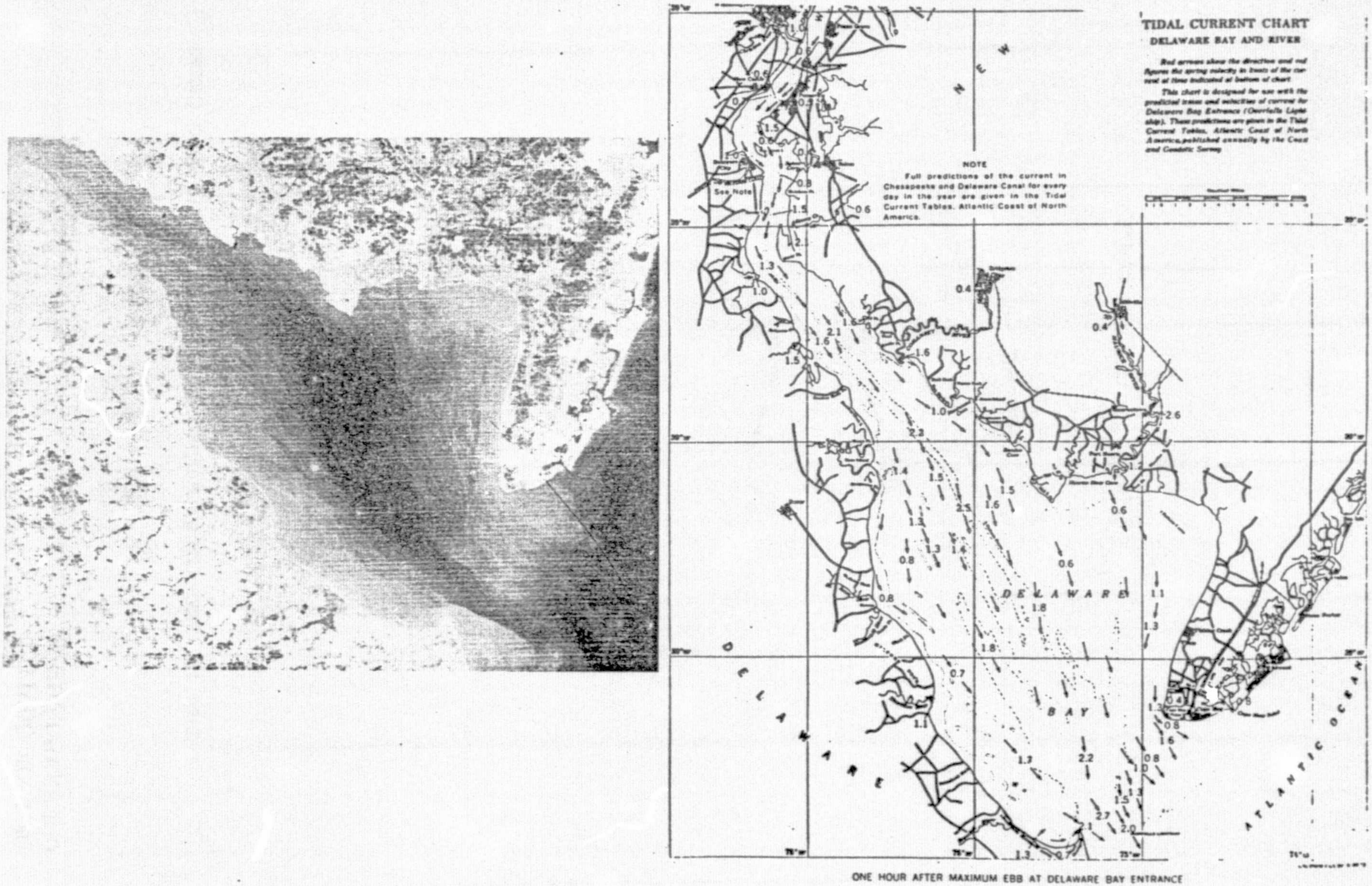

FIGURE 10. PREDICTED TIDAL CURRENTS AND ERTS-1 MSS BAND 5 IMAGE OF DELAWARE BAY TAKEN ON FEBRUARY 13, 1973 (I.D. NO. 1205-15141).

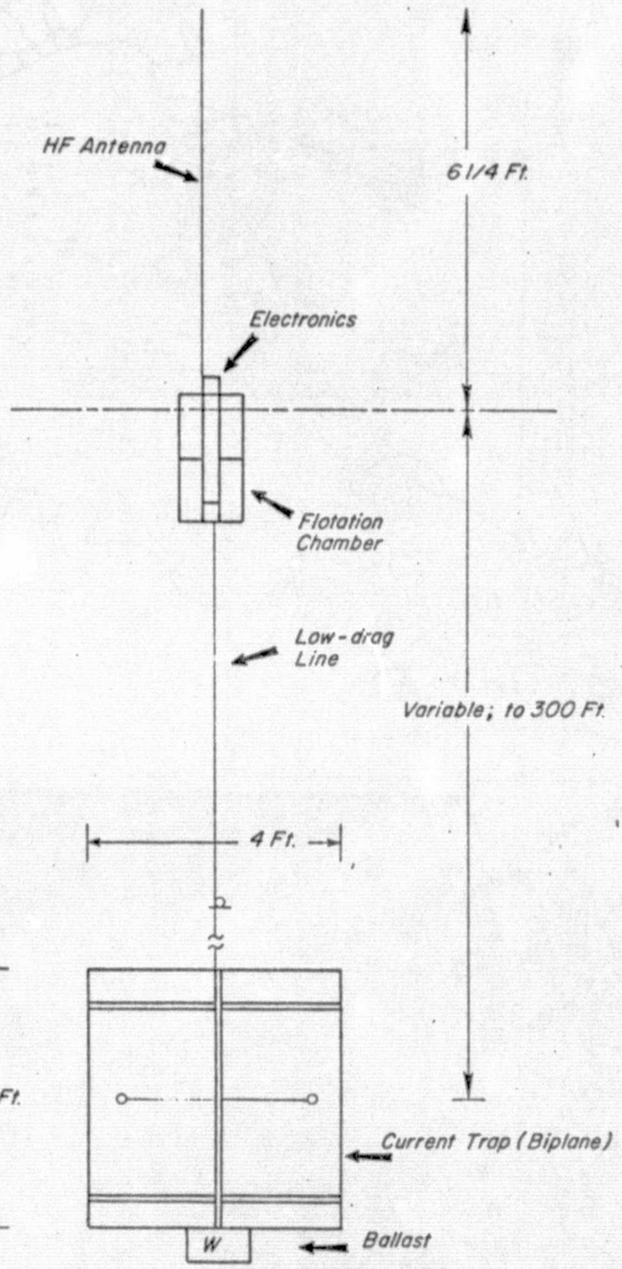

FIGURE 11. DEEP CURRENT DROGUE WITH LOW PARASITIC DRAG (MODEL 3).

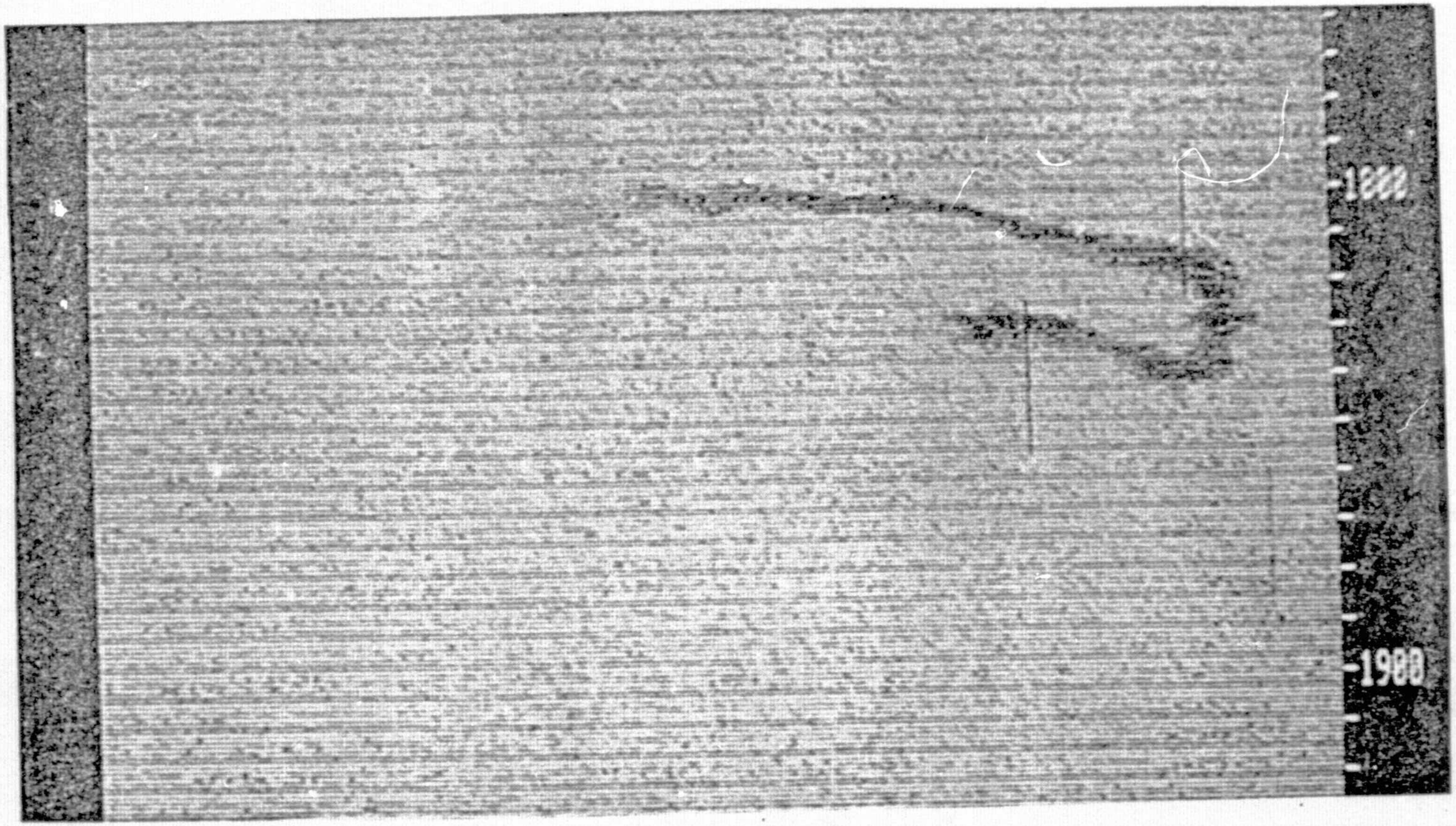

FIGURE 12. ENLARGED DIGITAL ENHANCEMENT OF ACID WASTE PLUME IMAGED BY LANDSAT-1 ON JANUARY 25, 1973.

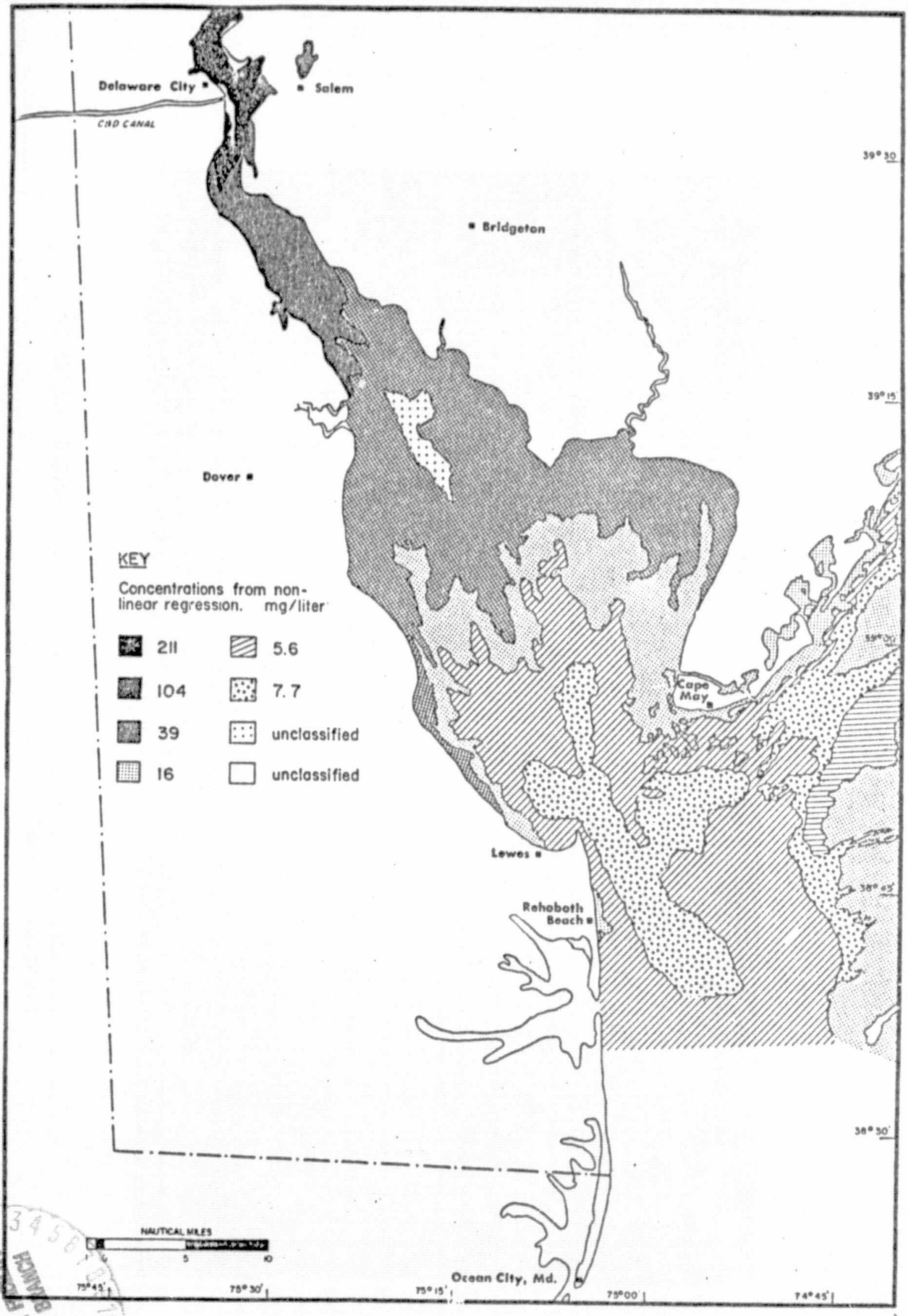

FIGURE 13. SEDIMENT DISTRIBUTION MAP.